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SOFT CAUSES WITH HARD CONSEQUENCES: THE ROLE OF ORGANISATIONAL FACTORS IN THE CREATION OF STRUCTURAL INTEGRITY.

JENS CHRISTEN ROLFSEN

Jens Christen Rolfsen, Safetec, PO Box 216, 0216 Oslo, Norway (corresponding author)

STEIN HAUGEN

Safetec and NTNU, Norway

JAN ERIK VINNEM

Preventor and NTNU, Norway

STIAN ANTONSEN,

SINTEF Technology and Society, Norway

JON ERLING HEGGLAND

Petroleum Safety Authority Norway

ELISABETH LOOTZ,

Petroleum Safety Authority Norway

ABSTRACT

Structural integrity is usually seen as a result of design, calculations, the correct choice of materials and good engineering practice in general. In this paper, we will shed light on organisational aspects that can influence structural integrity. Based on a review of accident investigations, interviews and a questionnaire survey, we will show how structural integrity is influenced by organisational processes that can generate latent conditions for major accidents. We will show that there are weaknesses in the way that the design and manufacturing of oil installations are organised.

We argue that these weaknesses can constitute a form of drift, making it more likely that the latent conditions for major accidents will be introduced and allowed to remain unnoticed. Major accidents are usually the result of combinations of several contributing factors.

We find two broad categories of challenges that may constitute latent preconditions for major accidents. First, our data indicates that the power and status of structural engineering professionals is declining. A form of cultural shift seems to have taken place, where the advice of the companies' top engineers is less authoritative than that which has hitherto been the case. The second category of contributing factors consists of deficiencies related to the integration of the different phases, from choice of concept to operation of the facility, and between the different actors involved in this process.

The paper concludes with a number of suggested measures for improvement.

Keywords: Offshore facilities, structural integrity, latent conditions, drift into failure.

1. INTRODUCTION

This paper presents an analysis of the way organisational factors can influence structural integrity. Based on a review of accident investigations, qualitative interviews and a questionnaire survey, we show how structural integrity is not only a question of good engineering, but also a product of organisational processes.

Accidents are, by definition, studied and investigated in retrospect. The investigation and explication of accidents related to the loss of structural integrity is a particularly challenging issue in terms of time, being that the root causes are sometimes introduced decades before the incidents. One example might clarify our point of departure.

One of the worst accidents in the North Sea petroleum activities was the capsizing of the Alexander Kielland rig. During a heavy storm, a support stay in the rig's load bearing structure broke and the rig turned upside-down in 20 minutes. The bridge that normally connected Alexander Kielland to a neighbouring platform had been removed due to the weather conditions, leaving the personnel with few possibilities of escape. The root causes of the structure's collapse were traced back to weaknesses introduced in the welding of the structure at a yard in France years before. This is a classic example of latent weaknesses that, in particular circumstances, can combine with active failures to create a major accidents (Reason, 1997).

We wish to put the notion of latent conditions at the centre of this paper. Instead of studying the consequences of latent conditions for accidents that have already occurred, we wish to shed light on the mechanisms that may generate the latent conditions for future accidents.

To this end we will combine Reason's well-known perspective on latent failures with the concept of ‘drift’ as described by Dekker (2011). Our aim here will be to describe the conditions that can generate latent conditions for major accidents, those related to loss of structural integrity. We will show that there are weaknesses in the way that the design and manufacturing of oil installations are organised. We will argue that these weaknesses can constitute a form of drift, making it more likely that latent conditions for major accidents can be introduced and are allowed to remain undetected.

1.1 Background for this study

There has been an increasing number of reported structural incidents on the Norwegian Continental Shelf (NCS) over the last three years.

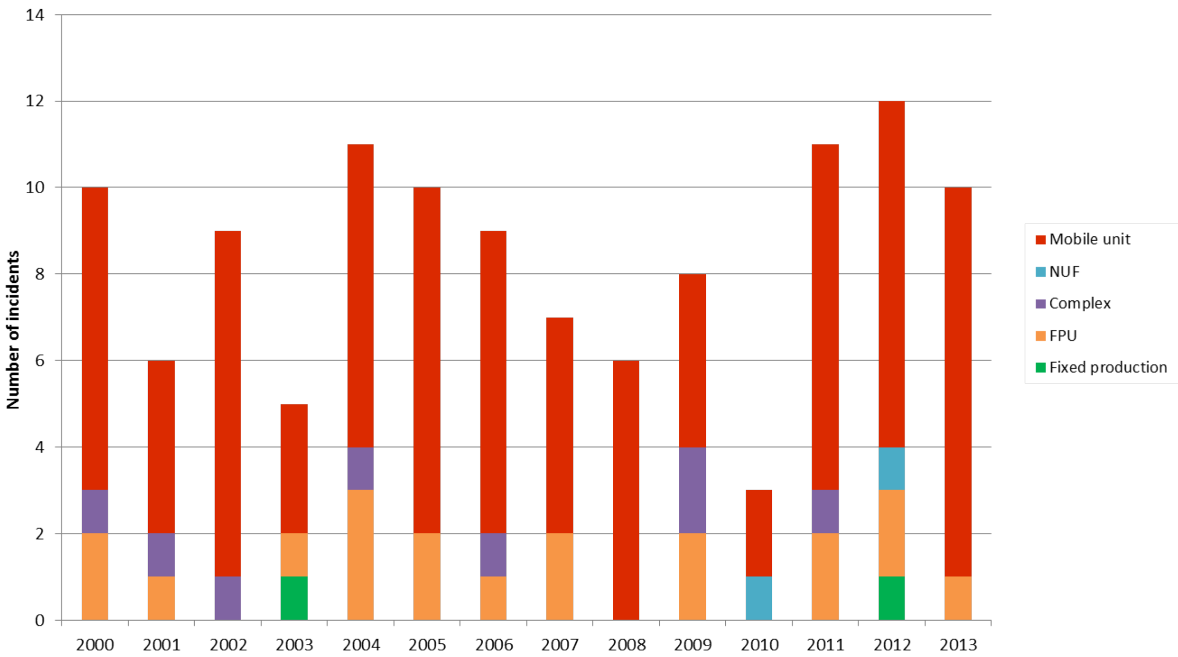

Figure 1 shows the number of reported structural incidents in the RNNP reports from 2000 to 2013.

Historic accidents, such as the afore-mentioned loss of the Alexander Kielland platform in 1980 where 123 people died, have forever changed the perception of safety and the potential of structural incidents in the petroleum industry. These phenomena, combined with increasing numbers of structural related incidents, have caused the Petroleum Safety Authority Norway (PSA) to initiate a comprehensive study into the causes and possible mitigating measures related to structural incidents. This study is aimed at parties involved in petroleum activities on the NCS, but should also be considered relevant both to similar operations worldwide and to international research on major accidents. The results of this investigation are published in Chapter 10 of the RNNP's main report for 2013 (PSA, 2013). The chapter also includes a similar study into maritime incidents, but the results from this part of the study will not be presented here.

The main research questions addressed in this article are:

- How can organisational factors influence structural integrity?
- Are there mechanisms in the industry today that may create latent conditions for structural failure?

2. MATERIAL AND METHODS

The data from the study was gathered as part of the Norwegian Petroleum Safety Authority's annual assessment of trends in the risk level of Norwegian petroleum activities (RNNP). In the following section, we will give a brief introduction to the RNNP assessments in general, before turning to the gathering and analysis of data related to structural incidents.

2.1 Trends in Risk Level in the Norwegian Petroleum Activity (RNNP)

The PSA report, Trends in Risk Level in the Norwegian Petroleum Activity (RNNP), has been released on an annual basis since 2001. The RNNP project aims to measure and improve health, safety and environmental conditions in the Norwegian petroleum industry, both offshore and onshore. The project includes indicators related to major accidents, personal injuries and working environment factors:

- Incident data (structural and maritime incidents, well control incidents, hydrocarbon leaks, personal injuries etc.)
- Data describing the performance of technical barriers
- Maintenance data
- Working environment indicators (noise, ergonomics and chemicals).

Multiple methods, both quantitative and qualitative, were used to investigate and monitor changes in risk level. Interviews, field work and a survey targeted at all employees on facilities on and offshore were used alongside more traditional incident and near-miss reports.

2.2 The present study

The study was performed by an interdisciplinary research group from Safetec, Sintef and Preventor. The objective of establishing an interdisciplinary team was to ensure that technical, organisational and human causes were all identified in the study. The study was based on the collection of information from different types of data sources and a subsequent analysis of the data collected. The use of several data sources enables the comparison and verification of different types of information against each other. The four main groups of information sources used were as follows:

1. Professional and research literature
2. Incident investigations
3. Interviews with industry experts
4. A questionnaire-based survey targeted at a wider selection of industry experts

During the data collection phase, provisional results were used to target further work. For example, the interview guide was adjusted in order to obtain more complete information about topics identified in the first interviews. Similarly, the questionnaire was also created on the basis of results from the other data sources. Information collection therefore developed as the work progressed.

The study was only possible due to the great willingness of individuals and companies. Key information for the study was collected from the professional community within the Norwegian petroleum industry, a body of information which is comprised of the findings of key groups of participants in the domain. A total of 85 people contributed to the study (44 interviewees, 41 questionnaire respondents), comprised of a broad sample of those who are considered in the industry to be experts on the topics covered by the study. Hence, interviewees were asked to suggest people who should be interviewed in their capacity as recognised experts. As the gathering of data progressed, a pattern emerged showing that the names given were already on the list of contacts. Similarly, many of the people proposed as possible questionnaire respondents had already been interviewed.

It may also be mentioned that, in an international context, it is rare for companies to put forward investigation reports and informants. In connection with previous causal studies carried out under RNNP (2010 and 2011), the PSA has received feedback at presentations of findings at international conferences demonstrating that it is 'highly unusual' internationally for companies to assist with investigation reports and informants. It is gratifying to see that the tradition in the Norwegian petroleum industry of sharing experiences and contributing to better insight into the causes of incidents with major accident potential has also continued in respect to this study.

In the following sub-chapters, the work on the four data sources will be described. By way of conclusion, there will also be a brief description of how the overall analysis was conducted.

2.2.1 Literature study

In the literature study, relevant national and international research linked to structural safety have been identified and analysed. The objective was to investigate whether there was literature available to help improve knowledge of and insight into causal factors and preventive measures associated with structural incidents.

Using a list of search words, general search engines (such as Google Scholar) were employed, as well as searches in OnePetro, a database especially devoted to the oil and gas industry. In addition, a number of reports from various research organisations, consultancy firms and the authorities were used to identify key contributions to the body of literature. The main focus was directed at references from the oil and gas industry in the last 10-15 years.

A total of 145 reports and articles were identified. These were treated as follows:

- An initial rough sorting of the 145 identified data sources was carried out, mainly based on their titles. It was performed by the project team's specialists, reducing the number of relevant sources to 70.
- The summaries of these 70 sources were reviewed to further rank their relevance. The sources were also sorted by topic and type of facility.
- The sources assessed as being most relevant, totalling 48, were then reviewed in detail. Of these, 39 were published between 2000 and the present day. This detailed review entailed analysing the sources in terms of whether, and how, they shed light on causal factors for structural and maritime incidents.

2.2.2 Investigations

The review of investigations was based on four investigation reports received from the PSA. These investigations were carried out by operating companies following incidents on the NCS. Only investigations from 2000 or later were included. Before then, we observed that there were fewer investigations and a weaker analytical foundation. However, the base data was extended to include the Sleipner accident in 1991 because it is the last major accident caused by structural factors to have occurred in Norway. Therefore, it is an accident for which a lot of information is available, being that there have been few structural incidents with a major accident potential involving fixed production facilities.

2.2.3 Interviews

Interviews with the companies' experts on structures and marine systems constituted an important part of the core data for the survey. The sample of informants is best described as a strategic sample. The interviewees were selected by asking the companies to indicate their principal specialists. The purpose of the interviews was to gather experiences associated with causes, challenges and future measures within structures.

The interviews were seen as critical for gathering information from professionals who had expert knowledge and experience of structural integrity. We invited the companies to nominate their leading experts on structural integrity, in order to assess what these experts considered to be the most important challenges to structural integrity. The invitation was made on behalf of the Petroleum Safety Authority of Norway.

In total, 38 interviews were conducted with 44 industry specialists. There are grounds for assuming that the interviews represent a good selection of Norway's prime expertise in the area. The interviewees were asked whether they had suggestions of other people who should be interviewed. As a result, the number of interviews was expanded compared with the original plan.

Priority was given to employees of engineering companies (14), operating companies (12) and rig owner companies (11). In addition, the interviews covered a total of seven people from the relevant authorities, from a classification society, and from the research and consultancy domains. Overall, the interviewees represented 14 organisations. The interview topics varied according to the subjects' background and expertise.

The interviews were conducted between October and December 2013. 34 of the 38 interviews were conducted face-to-face, with the remainder taking place by phone. With four exceptions, the interviews were conducted by two members of the research team in order to document the interviews satisfactorily without recording them and to bring both engineering science expertise and social science expertise to the interviews. Recording equipment was not used to emphasise the complete anonymity of all informants. This issue was seen as important, being that the study was performed on behalf of the PSA. Issues of safety can be a sensitive topic in terms of defining the relationship between companies and the PSA, while complete anonymity was seen as a prerequisite for data quality. All informants appeared very frank and we have no reason to believe that relevant information was withheld from the interviews. Each interview lasted about one hour.

Before the interviews began, an interview guide was prepared with a list of relevant questions and topics. In addition to specific questions and topics, the interviews also included completely open questions such as "in your view, where is the greatest risk in terms of structural incidents/maritime incidents?" and "if you had all the necessary power and means available to you, what would you prioritise to improve safety within these areas?" By way of conclusion, the interviewees were also asked if there were other topics they had expected to be questioned about, or whether there were other topics they would like to raise. This possibility was raised to ensure that it was not exclusively the interviewers' interests which determined which topics were raised.

Extensive notes were taken during each interview to provide a basis for writing minutes. After each interview, the interviewers produced a brief summary, identifying important outcomes from the interview. This summary served as input for topics which should be followed up in further interviews, and to refute or confirm earlier hypotheses and findings. Similarly, after around one third of the interviews had been concluded, a summary was produced by the entire research team, one producing input for new topics and further targeting of the remaining interviews.

2.2.4 Survey questionnaire

Interviews are an effective, but also time-consuming method of collecting data. In order to ensure access to views from a wider sample of professionals, an electronic questionnaire-based survey was also conducted. The purpose of this survey was partly to supplement the data gathered through the interviews, and partly to investigate more closely some of the topics that the interviews had identified as interesting.

To procure relevant respondents for the survey, direct contact was made with a total of 17 operating companies, 14 drilling contractors, four engineering companies, three inspection and maintenance organisations, and five equipment suppliers. Contact was also made with classification societies and universities. All were requested to provide the e-mail addresses of specialists.

Some companies chose not to participate in the survey. They stated that they did not have in-house competence. Some of the names proposed had already been interviewed and were not asked to participate in the questionnaire. 34 organisations in all responded positively to the invitation. These included 12 operating companies, ten drilling contractors, three engineering companies, two inspection and maintenance organisations, five equipment suppliers and two others. In total, questionnaires were sent out to 76 e-mail addresses and 41 responses were received (response rate 54).

The survey asked a number of open questions concerning causes and measures associated with structural incidents. These were answered as free text. The respondents were also asked to answer 17 standardised questionnaire items along a 5-point Likert scale.

The free text responses from the questionnaire were analysed in two stages. Firstly, they were sorted into thematically similar groups. The crux or essence of each response was then allocated to the main causal categories: human, technical and organisational. The standardised items were only analysed as descriptive statistics and they were used to elucidate key topics from the interview survey, where appropriate.

2.2.5 Processing of collected data

Once all the data collection activities were underway (but before they were completed), a working meeting of the study's project team was held, at which provisional findings and conclusions from all the sources were reviewed and discussed. The purpose of this was primarily to see if there were obvious results that it would be natural to highlight, if there were topics that should be pursued in further activities, and also if there was a need to adjust the data collection process in other ways.

A working meeting was then held for the entire project team to conduct a systematic review of the data from all the sources in order to identify important findings and observations. This was done using two approaches:

- Firstly, the different phases in project execution (see figure 2) were assessed to see if it was possible to associate observations with each of the phases. For this, assessments were made separately for field development and for the construction of a drilling facility. In terms of drilling facilities, by far the majority of findings related to operations, but for field developments this division into phases worked very well.
- For each phase, the different participants were assessed to see if there were observations that could be linked to different groups of participants, such as ‘operating companies’ or ‘rig owner companies’.

3. THEORY

There has been much research undertaken on major accidents, while a number of theoretical perspectives have also been promulgated in the research literature. However, most accident models do include the notion of root causes, where accidents are seen as the product of multiple long and complex chains of events. One important theoretical framework has been James Reason's book "Managing the Risks of Organisational Accidents" (Reason 1997). Reason builds on the energy-barrier perspective instigated as far back as in 1961 (Gibson 1961, Haddon 1980), but makes an important enhancement to this perspective with his introduction of the familiar ‘Swiss cheese model’. This model illustrates not only that there may be active faults causing barriers to fail, but there may also be latent preconditions with a potential for leading to failure. As Reason points out, latent preconditions may be introduced a long time before an incident occurs; for example, in the engineering or construction phase of a facility, or through modifications to or the operation itself of a facility.

In line with Reason, the term ‘causes’ is used in a broad sense within this context and not only in relation to factors that lead directly to an incident occurring. Causes may also include factors which are evaluated as having had an influence on an incident, either by actually or potentially having contributed to increasing the likelihood of an incident occurring. Such an understanding of the concept of causation makes it natural to examine not only direct causes or triggering causes, but also to search further back along the incident chain to discover underlying causes.

One challenge of such a perspective is that the relationships between cause and incident may be perceived as weak and indistinct. In fact, most latent preconditions do *not* lead to major accidents. This is one of the paradoxes of safety management in relation to major accidents, being that they are rare and often the result of combinations of events and causal factors that are rather unlikely. However, in order to prevent major accidents we have no choice but to include such factors. As long as we fail to expect to find a single smoking gun that can be directly linked to a major accident scenario, we are left searching for the small errors, those for which it can be logically argued that there may be a potential relationship between causes and incidents. As a consequence, this study has looked for human, technical and organisational factors which may have affected, or which are capable of affecting, the incident types being studied.

Two other theoretical perspectives which have been significant for assessing the material are Turner's ‘Man-Made Disasters’ (Turner and Pidgeon 1997) and Dekker's ‘Drift into Failure’ (Dekker 2011). Turner develops an accident model based on a metaphor from epidemiology, when he concluded that major accidents could be regarded as having an ‘incubation phase’ where symptoms of illness were present, but not understood. This is very much in line with Reason's concept of latent conditions; here Reason has also used the term *latent pathogens* to explain the Swiss cheese model (Reason 1997).

Another key element of Turner's theory is that there are nearly always individuals or parts of an organisation that were aware such developments were taking place. The challenge was to detect these trends, see them in context and correct them in time. Important and relevant factors in this perspective are information flow within and between organisations, and also an overview and understanding of relationships. This acquires extra relevance due to the complexity of organising, in particular, the engineering and construction of facilities. Many participants are involved, those with varied experience from different countries and with diverse cultures, with the potential therefore to exacerbate potential problems with information flow.

A similar model of accidents is present in Dekker's (2011) model of ‘drift into failure’. Dekker's drift model concerns slow trends in development that involve gradually increasing risk. Being that the gradual increases in risk progress so slowly, the development sometimes goes unnoticed because people are habituated to the small changes. Most theories and analyses of drift are related to the operational phase, being that they try to explain how and why work practises are likely to change over time because they are adapted to changing circumstances in the work context.

In the present analysis, we will relate the concept of drift just as much to decisions, as to work practice. Decisions regarding which practices considered safe enough are also likely to drift over time, being that they are influenced by market conditions, oil prices, changes in regulation, major accidents, media coverage and so on. An offshore facility is also a patchwork of parts constructed by different companies throughout the world. When these parts are fitted together, there can be major or minor inconsistencies that could not be foreseen at the drawing board. There will thus be several instances in the design and construction phases where trade-off situations arise, and where choices and adaptations are made that can influence structural integrity.

The combination of Reason's notion of latent preconditions and concepts of drift allows for analysing the contexts in which latent preconditions are created. The aim of this paper has therefore been to describe mechanisms in the industry today that may introduce latent conditions for structural failure. As we will show, there are developments within the oil industry can be seen as a form of drift that can introduce latent preconditions for future accidents.

4. RESULTS AND DISCUSSION

4.1 Literature study and investigation reports

The literature study and review of accident reports have provided a limited quantity of useful information to the project. Except for very general observations about the importance of organisational factors, the literature did not provide much information on the contributing causes to structural incidents; in itself an interesting finding, and will be discussed later. Further, out of a total of 40 structural incidents that have been reported to PSA since 2000, only three investigations exist. Below is a brief description of the incidents based on the investigation reports.

In 2006, the deck of a fixed production facility was struck by a series of waves. The incident had a major accident potential being that the facility had not been shut down and the workers had not been sent ashore following an extreme wave forecast. The investigation report did not detect damage to the primary structure. However, the incident had the potential for such damage. The investigation report identified underlying causes of the incident, including an unclear understanding of the procedure for de-manning and shutting down the facility in the event of bad weather. In addition, the investigation report noted that there was poor risk comprehension in respect to allowing personnel to remain active on deck. The offshore installation manager was new to the job and did not have extensive experience of offshore facilities. Moreover, adequate risk assessments for the facility had not been made.

In 2002, three continuous cracks were discovered in horizontal braces on a mobile drilling facility. The cracks were detected through the leak detection system recording water ingress. The facility was taken to shore as quickly as possible. The investigation report discovered that the direct cause were the cracks starting in welds in reinforcement plates that had occurred in connection with a previous modification. The welding method did not match the engineering design expectations, and the report describes how this may indicate a failure in communication and quality control. It was further pointed out that the quality control of the drawings carried out by the classification society did not detect any change between the engineering design drawing and the solution actually employed. In addition to short-term measures directed at the facility involved, the report recommends undertaking further investigations to establish underlying causes. The research team does not know if this was done, or which activities it may have resulted in.

The latest incident tackled in the literature also dates back to 2002. Problems arose during work on installing five out of eight piles for a relatively small steel jacket platform. The problems arose during the installation phase, caused by a combination of minor manufacturing defects and an especially dense layer in the formation. The difficulties were resolved before production start-up and did not have a major accident potential. On this basis, the incident was not of a structural nature, and was not examined further.

4.2 Interviews

Being that the number of incident reports was very low, the results from the interview study were particularly important. The interview material contains data from the participants' own experts on structural incidents. The interviewees are involved in the choice of concept and initial design, detailed design, and the construction and operation of the facilities. Figure 2 gives an overview of the different phases that are involved from the design of facilities to the operations phase.

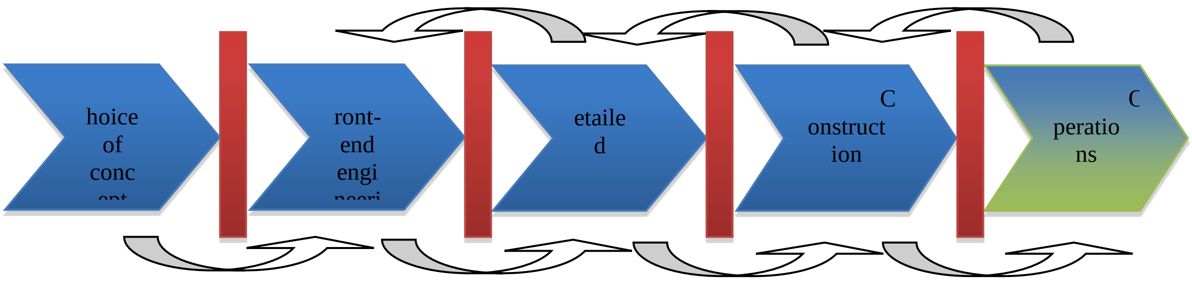

Figure 2: A simplified model of the stages of design and development projects. Adapted from NORSOK S-002.

Results from the analysis will be presented for each of these phases. We will use the interviews as our basis and supplement them with relevant data from the literature survey, questionnaire-based survey and relevant investigations in the discussion.

4.2.1 Choice of concept and initial engineering

The first activity in designing an offshore facility is the choice of concept. ‘Concept’ here refers to the type of installation chosen as suitable for certain tasks and a certain location (e.g. condeep platforms, tension leg platforms, jacket structures etc.). One key topic for the informants, which they highlight in the interviews, is related to the importance of choosing robust design solutions in the early engineering phase. The interviewees used the concept of ‘robust’ solutions with several meanings. Sometimes this term refers to engineering the primary structure with good safety margins, in order that it can withstand failures of individual components without catastrophic consequences occurring (redundancy).

This use of the term may also be associated with what we call passive safety[1]; for example, in semi-submersible production facilities.

As an example of passive safety, several interviewees from engineering companies and operating companies argued for isolated ballast systems in the four quadrants of the hull. This makes it physically impossible to move ballast water between the quadrants which, in turn, eliminates the potential of a type of operational error which can have serious consequences. For example, valves which are unintentionally open may lead to flooding and potentially worsen the situation. Conversely, it was asserted that such a solution involving isolated ballast water systems could prevent the flexibility that might be desirable in certain operational situations. Discussions are currently in progress between engineering companies and operators concerning this type of solution for the NCS.

The term ‘robust’ was also used to characterise the structure's ability to cater for potential future needs. It was linked to, for example, the installation of new and heavier production equipment on the facility. One interviewee expressed it like this: "the platforms are constructed to be just too small for the needs right now". Experience shows that, over time, production facilities will undergo a series of modifications due to new equipment, changes in production, new fields being tied in etc. If an account has not been taken of such future needs in design engineering, it may be difficult to modify the facility without exceeding the weight it was originally designed for.

A third use of the term ‘robust’ refers to engineering the structure to make the force distribution in the structure as simple as possible. It was said that this makes it easier to verify the soundness of a concept through manual calculations and good engineering expertise. This activity, is considered, in turn, to provide extra assurance that safety has been provided for compared with being completely dependent on detailed software calculations in order to verify the concept.

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[1] Passive safety is understood to mean built-in safety or robustness that does not require activation by operators or automation systems in order to function.

For all these forms of robustness, there were some concerns that there had been a development over time where the operating companies had gradually chosen cheaper, less robust concepts. Cost-efficiency is given high priority in the industry, and some felt that this was accompanied by less of an emphasis on structural integrity and robustness. Seen in relation to Dekker's concept of drift, questions may be asked as to whether this constitutes a form of slow eroding of safety margins related to structural integrity.

It was primarily informants from operating and engineering companies who discussed conceptual choices and initial design engineering. The following is a thematic review of the findings from these interviews, alongside associated results from other data sources.

4.2.2 Conceptual understanding and engineering expertise

The informants were generally clear that good choices in the concept phase require access to highly qualified engineers, those with wide experience of offshore projects. A number of interviewees highlighted ‘conceptual understanding’ as a key expression. This indicates the importance of one of the competences referred to in the section above; namely, the skill of being able to perform simple static load calculations according to a concept working at an overall level, without having to undertake time-consuming and costly analysis. This requires a holistic understanding of what makes structures robust and what constitutes the most critical factors for the integrity of the structure.

One example mentioned in the interviews was that of the engineer who could sit down for a couple of days in his office with pencil and paper to come up with a finished main concept. At the same time, according to the informants, conceptual understanding is important for understanding and evaluating the entirety of the structure to be built, precisely to ensure that a sound solution is achieved. It has also been said that good conceptual understanding is a prerequisite for being able to ask critical questions about the choice of concept at an early stage.

A number of interviewees stated that there were fewer engineers able to perform such manual calculations, while engineering expertise had increasingly shifted to performing software-based analyses. In other words, there are signs that fewer people now have good conceptual understanding. It is important to emphasise that it is not only older engineers expressing concern that there are fewer people in possession of the more ‘old-fashioned’ engineering craft. Consequently, these concerns should not be seen as a conservative view that ‘everything was much better before’. Nonetheless, it should be interpreted as a real concern about a lack of basic proficiency in calculations that makes the structures over-analysed and under-designed.

4.2.3 Have the structures become less robust[2] as a result of more precise analytical methods?

Estimations and detailed software calculations have been mentioned above. One view put forward here is that the transition to more detailed calculations has reduced the margins in the structure and thereby, in practice, reduced safety. However, the interviewees' feedback varied on this subject. Some supported this view, while others asserted to the contrary that this approach had produced safer solutions. There was no clear pattern of variations in the data taken from the interviews and questionnaires across groups of participants. At the same time, the results of the questionnaire-based survey show that 46 per cent agreed or fully agreed with the statement that "better and more powerful analytical tools have led to less robust structures". Together with the results from the interviews on this topic, we take this as a sign that more knowledge is required about whether analytical methods affect structural safety and how they do so.

4.2.4 Poorer conditions for specialist structural engineering expertise

Several of the interviewees, especially those from the operating companies, argued that there are mechanisms in the industry which make it more difficult to ‘stay the course’ professionally and cultivate specialist expertise in structural technology. Some asserted that the career system does not reward those who stay in a single discipline, while some claimed that the status of employees with specialist structural engineering expertise has declined in recent years. Based on these interview findings, we constructed one of the statements for consideration in the questionnaire-based survey as, "In my organisation, status is accorded to experts in structural engineering". 27 per cent of the respondents, representing both operating and engineering companies, disagreed or fully disagreed with this statement. This confirms that there are challenges associated with valuing structural engineering expertise.

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[2] Note that the term ‘robust’ is used here in the sense of ‘design the primary structure with good safety margins and so that it withstands failures of individual components without catastrophic consequences’. Ref. NORSOK N-001 chap. 4.7 Robustness assessment

Some of the companies taking their place among the groups participating in this study have arranged increasingly for their employees to switch roles and work tasks at regular intervals. This is a positive measure in terms of developing professional scope, but it would result in the creation of more professional generalists than specialists. Although the results from the questionnaire vary, we consider it important to listen to those experts who, in the survey and interviews, expressed concern for the status of their own specialism.

4.2.5 Changes in the burden of proof for assessing safety in structures

One key finding in the study is that several interviewees from engineering companies and operating companies were finding it more difficult to succeed in putting forward viewpoints critical of conceptual choices on the part of their own organisation's management, or in the transition from one project phase to another. Illustrative statements emerged which indicate that conditions for "'harbingers of bad news' have deteriorated".

Examples of statements from the interviews concerning this include:

- "*Does the profession have a good enough status? No, there are many examples of technical specialists being overruled by the business admin side.”*
- *"A culture which assumes that management should be able to override technical experts on technical matters.”*
- *"When you have a team on site, and there's a visit from Norway, the management would rather hear the optimistic versions from the yard than bad news from the visitors from Norway."*
- *"The advances of the economists, much more focus on optimisation and more immediate value than before."*
- *"It is optimism and positivity which are career-enhancing."*
- "*Now you have to prove that a solution does not work instead of having to prove that it actually does work.*"

Based on the interview material, one may wonder whether, over time, there has been a slide towards a stronger focus on costs (present value) and progress in these projects. Key specialists in several operating companies have noted that it is more difficult than before to adopt the role of devil's advocate and pose critical questions about structural safety once projects have passed the concept phase. This may contribute to weakening the control mechanisms aimed at detecting small faults before they contribute to a major accident.

The industry has become more cost focused in recent years. Among other things, this is a result of an increase in the cost level associated with developments, entailing that profit margins are not the same as they were with earlier, large developments. One measure here is the trend over time in the oil and gas price that is necessary to make new developments profitable (the equilibrium price). Figures from the government’s White Paper 28 (2010-2011) show that, whereas the equilibrium price for new field developments in 2004 was around NOK 100 per barrel, the equivalent price in 2009 was more than NOK 300 per barrel. In periods of an important and natural need to cut costs and increase efficiency, it is, as Rasmussen (1997) describes, particularly important to maintain the right balance between safety, on the one hand, and costs, on the other. It is therefore crucial, among other things, to search for signs and signals of an incorrect balance, and so important to maintain a safety culture where harbingers of bad news are heeded and rewarded.

It seems that important changes are in progress in the burden of proof linked to safety. Whereas specialists previously assumed that a structure was not safe until the contrary had been proved, key informants now say that is more a case of assuming that the structure is safe until one has proved that it is not. This type of switch in the burden of proof was applied to earlier accident investigations; notably after the Challenger space shuttle accident in 1986 (Vaughan, 1996). There appear to be differences between companies in this area. While some find that the situation has deteriorated significantly in recent years, others refer to organisations where there is a lot of scope for bringing up concerns about robustness, despite potential increased costs and delays. The data does not provide a basis for drawing any clear conclusions about differences between and within groups of participants. However, the findings do illustrate that the petroleum industry's focus on safety culture should not be limited to operational personnel in the operations phase. Decisions concerning choice of concept must also respond to conflicting goals of various kinds and will hence be capable of being influenced by the organisations' safety cultures.

4.2.6 Detailed engineering, fabrication and installation

Decisions taken in respect to conceptual choices constitute important framework conditions for all subsequent phases. They are not be significant solely in terms of the progress and cost of field development, but also in terms of major accident risk. Progress and costs are affected due to faults being discovered that may require comprehensive redesign, which is both costly and time-consuming. However, the major accident risk is also affected, due to the structure being less able to withstand faults that go undetected. In these cases where a concept with good passive safety has been chosen, it takes more than flaws introduced in detail engineering and fabrication to cause a major accident.

4.2.7 Follow-up of detail engineering and fabrication

In recent years, there has been a tendency for more and more detail engineering and fabrication to be performed outside of Norway and for interaction to take place amongst a multitude of stakeholders. Different engineering companies located in Norway, UK, India or Poland may now perform work on different phases of a project. There may also be several yards in different parts of the world involved in parallel construction of the different parts of a facility. The research team did not take a position on whether this is a good development or not. However, the interviews and questionnaire have yielded some information about which problems need to be addressed and which may be relevant to major accident risk.

Much of the information that emerged relates to building in Asia, but there were also examples from engineering companies with similar building problems in and the use of sub-contractors in other parts of the world, including Eastern Europe. Although the discussion primarily focused on Asia, one should not underestimate the significance of similar challenges in situations where participants have used suppliers with limited experience of supplying to the Norwegian offshore industry.

One of the greatest challenges highlighted in the study was the follow-up of detail engineering and the fabrication phase. This is raised, in particular, by the engineering companies; for example, "Difficult and expensive to achieve good follow-up of yards in Asia – creates a poorer connection between engineering and yard". Another similar example is, "Building in the Far East requires a large team for follow-up". The free-text answers to the questionnaire also include a number of similar statements, such as "Operators do not devote enough resources to follow-up of yards with little building experience of relevant installations". The participants in the questionnaire-based survey were asked their view on the statement, "The fabrication process is properly monitored by operators and engineering companies". 45 per cent fully disagreed or disagreed with this statement, and these respondents were divided between operating companies, rig owner companies and engineering companies. Therefore, concerns relating to whether there is adequate follow-up in the fabrication phase also emerged here.

The interviewees related their comments to both project progress and safety in the delivered facility. A lack of follow-up creates a need for both redesign and modifications, leading to time pressure that may, in turn, be to the detriment of quality in engineering and fabrication. This is a classic conflict of goals, as described by Rasmussen (1997). At the same time, it is apparent that a lack of follow-up represents both a safety and financial risk.

A majority of the interviewees perceived an increased need for follow-up when constructing in Asia; the most important reason was the engineering companies’ and yards lack of experience with engineering and construction for Norwegian conditions, in accordance with Norwegian requirements and standards. A lack of knowledge of NORSOK standards and Norwegian regulations, especially of the background to the standards and regulations, was mentioned as one factor. Reference was also made to a lack of knowledge of the loads the structures have to withstand and the way in which they are used.

One possible interpretation might be that the important safety implications of the particular weather conditions on the NCS and the functional requirements of the Norwegian regulations were both accorded too little attention in communications between requisitioners and suppliers in the planning, engineering and fabrication processes.

It must be noted that the interviewees did not necessarily claim that foreign yards did a worse job than Norwegian ones. Nor it is a case of foreign engineering resources being less competent than Norwegian engineers.[3] The research team's understanding is that it is primarily a question of less experience and that one would have probably found the same problems with a Norwegian yard in possession of none or little previous experience of offshore activities. One comment that may relate to this came from an interviewee who works for a rig owner company: "If you know what you want before you start, you build in Asia, otherwise you build in Norway". This observation entails that standard solutions (which may well have been built before), and solutions where detail engineering is well advanced, are more easily delivered in Asia.

[3] The interviews raised examples of Norwegian solutions for use abroad having proved unsatisfactory due to a lack of knowledge of local environmental conditions and loads. This illustrates that it is more a question of familiarity with the environment in which the structures will be erected.

One possible solution to the challenges outlined here, that which is pointed out by many of the informants, is closer follow-up of the suppliers involved (both engineering companies and yards) up to the point where they have developed the necessary experience. For this, the companies need to obtain and use resources in the form of personnel, time and skills in order to perform a close follow-up of the executing party's competence, acquiring both an understanding of what is to be built and an understanding of the loads to which the structures will be subjected once installed.

In this context, it would also be logical to mention the Norwegian Petroleum Directorate's report from 2013 on "Evaluation of projects implemented on the Norwegian shelf" (Norwegian Petroleum Directorate 2013). This report covers five projects with approved development plans in the period 2006-2008 and with investments of at least NOK 10 billion. The report draws attention an important cause of overruns and delays; namely, the underestimation of the need for follow-up of new building projects abroad. The report also mentions as further important reasons a lack of NORSOK and regulatory experience among the yards building the facilities. The Norwegian Petroleum Directorate's focus was on projects that suffered large delays or cost overruns, confirming that follow-up is important for projects' finances as well as their safety.

4.2.8 Project execution and cultural differences

It is well-known that there are national cultural differences between Norway and, for example, Singapore, Korea and China (see, for example, Hofstede, 1980). Although one should be wary of creating cultural stereotypes, there are some differences worth mentioning in working life traditions between countries in North Western Europe and countries in South East Asia. One key element is that, in Norway, organisations are most often flat and informally structured. Characterised by a low power distance (ibid), each individual has a large scope of action and it is generally acceptable to take the initiative to communicate and cooperate across organizational departments and to speak up about concerns and disagreements. In many Asian cultures, organisations tend to be somewhat more hierarchical, with a more marked distance between managers and other employees. Such cultural differences can cause some confusion when it comes to collaboration in engineering projects. In terms of project execution, the interviewees said the following about conditions in Asia:

- "*Everyone expects to receive clear orders from their manager and to do their best to fulfil these orders to the letter*."
- "*One does not question orders received, regardless of whether they appear to be correct and sensible or not.*"

Obviously, this has nothing to do with what is regarded as a ‘correct’ or ‘good’ culture. The point is rather that different cultures consist of different conventions, leading to different expectations and norms in regard to what people see as the right way to perform one's job. Possible effects may include:

- Managers must be much clearer in their messages than in Norway. If orders are unclear or ambiguous, one cannot expect to be asked questions about what was intended in order to clear up any uncertainties.
- Interdisciplinary cooperation cannot be expected to progress as easily as in Norway. The hierarchical structures can make this problematic.

Here, closer follow-up and, not least, more resources for following up may help counter these problems.

4.2.9 Operations

The study collected a lot of information indicating that information exchange and learning between phases and participants could be improved. This was confirmed by both the interviews and the questionnaire. This subject was also of key interest in some of the investigations.

The investigation of the structural incident with waves on deck showed, for example, how challenging it can be to ensure that the assumptions and results of risk analyses are communicated in a way that ensures that affected personnel understand the implications and act accordingly. Even though the platform management was familiar with the de-manning procedure and had trained in such situations, they were not clear that the combination of wave height and forecast strong winds required evacuation in the case. The need for transmitting information back from the operational phase to the engineering phase was raised in many interviews. In particular, many of the statements from the engineering companies can be linked to this. In regard to the theoretical perspectives outlined in section 2, this may be associated with Turner's "Man-made Disasters" (Turner and Pidgeon 1997), where a deficient flow of information between organisations and phases is propounded as a potential source of major accidents.

The key point to be made is that the engineering companies believe that they receive far too little information about how the structures that they have designed actually behave once they have been built and commissioned. The measures currently employed to feed information back are not perceived as adequate. Examples of statements include:

- *"No, in my experience, we get very little empirical data from the client. We never check the sums to find out if what actually happens out on the field matches our design analyses."*
- *"We get no feedback from the user organisations on how the structures are working. I often wonder how things have panned out for the structures over time."*
- *"Aside from the PSA's structural integrity seminar[4], there are no forums for information exchange."*
- *"When it comes to damage, we have had very little feedback about damage and corrosion to the structure. So, we don't know if the design criteria we use actually work."*

The questionnaire also touched upon the following topic, which was stated in the free text replies:

- *"Relevant information about structural incidents is not adequately fed back to the design domains. Here the authorities (the PSA) have a job to do."*

The participants were also asked their views on the statement: "experiences from previous structural incidents are only given slight consideration in the choice of concept and design". 35 per cent of the respondents agreed with this statement, the majority of them representing engineering companies.

The engineering companies highlighted a lack of information exchange as a challenge since it may lead to the repetition of deficient solutions.[5] Systematic transfer of operational data over time can provide a basis for improvements in regulations, the understanding of loads and their effect on structures.

One proposal to have emerged from the interviews (mentioned by many) was that practice should be strengthened in terms of surveying structures, which are now being decommissioned, to see where cracks have propagated, as the basis for checking assumptions and calculations made in the engineering phase. Section 50 of the Activities Regulations already contains a provision for this: "When facilities are disposed of, the operator shall carry out studies of the structure's condition. The results shall be used to assess the safety of similar facilities." Furthermore, the guidelines state that, "The examinations as mentioned in the fourth subsection, should particularly be carried out with a view towards projected new facilities and use of facilities beyond their original planned lifetime in mind." It seems clear that this point is not well-known in the industry; that is, if suggestions are being made that it should become standard practice. It should be noted that this provision was introduced a relatively short time ago.

The interviewees from the engineering companies also queried whether the knowledge possessed by the engineering teams concerning highly stressed nodes and elements on the facilities was adequately utilised. Inspection programmes have been developed to monitor the condition of operational facilities. Examples were given of inspection programmes having been developed with a percentage coverage of the nodes according with the engineering recommendations, but where the nodes that were actually inspected were selected on the basis of accessibility and not on the basis of the highest loading or criticality in terms of integrity:

”The nodes on the topsides were described in a report from [engineering company], which defined which were the most critical nodes. The inspection plan specified examining 5% of the nodes per year, but it was the same 5% that were inspected each year, and it was the most accessible and none of the most critical that were selected.”

In the questionnaire, 40 per cent of the respondents highlighted an increased focus on inspection and condition monitoring of operational facilities, in answer to the question about which risk-reducing measures should be implemented to safeguard the integrity of load-bearing structures. In the light of the discussions in this section, it is crucial that any increase in the level of activity in respect of inspections and condition monitoring also includes measures to ensure that information on the outcome of the activities reaches the relevant participant groups. This includes participants who prepare the foundation for inspection programmes (engineering or

[4] In recent years, the PSA has held an annual "structural integrity day", which the industry is invited to attend. This conference includes presentations tackling relevant problems associated with structures and safety.

[5] In a causation study of hydrocarbon leaks under RNNP 2010, 48% of triggering causes were associated with defective or poor design of the process facility. In following up this finding, the PSA contacted a number of engineering companies, who expressed a similar need for transfer of experience from the operating companies' running of the process facilities to the design domains, in order to prevent the repeat of inadequate solutions.

consultancy firms), those who evaluate results from the inspections (rig owners or operators) and the inspection enterprises that carry out the inspection work.

This very point was highlighted by the investigation group in one of the investigations discussed previously. They describe how inspections of the hull detected considerable corrosion without this leading to changes in inspection routines or maintenance activities. The inspection report does not describe inter-relationships between participants. Nonetheless, it appears clear that the information flows between them (the classification society, the rig owner’s company and yard) were deficient and that this reality contributed to the incident.

Statements also emerged from the operating companies indicating that there has been a limited systematic transfer of experience and learning between the companies. A couple of assertions illustrate this: *"I have never met up with other operating companies to share experiences"*; *"I know people and we chat but there is no formal cooperation".*

Overall, there seems to be less exchange of knowledge and experience between the phases and the participants than is desirable. The only formal communications forums mentioned by the informants were the PSA's structural integrity seminars and Joint Industry Projects (JIP) for professional inter-company cooperation. It should be mentioned that other relevant specialist conferences are also organised in the petroleum industry but findings from the study may indicate that these, on their own, are not perceived as appropriate forums for the exchange of more concrete operational experience.

5. CONCLUSIONS AND RECOMMENDATIONS

In the description of the study's results, we have provided a broad description of the various challenges that can arise in the process of designing, engineering and manufacturing an offshore facility. In the remainder of the paper we will relate the empirical description to the research questions and the theoretical perspectives introduced in sections 1 and 3.

As indicated, major accidents are usually the result of combinations of several contributing factors. Thus, efforts to prevent major accidents will involve searching for organisational conditions which, by themselves, may seem insignificant, but which, nevertheless, can serve as latent conditions that can come into play in particular circumstances. We have found several such conditions in this study. These conditions fall into two broad categories.

First, our data indicates that the power and status of structural engineering professionals is declining. A form of cultural shift seems to have taken place, where the advice of the companies' top engineers is less authoritative than what has hitherto been the case. Our informants attest that they have had to fight harder to make their voices heard, and that it is increasingly difficult to be the harbinger of bad news in engineering projects. The burden of proof is perceived to be shifting, from having to prove that something is safe to having to prove that it is dangerous. This shift is far from trivial. For instance, the devaluation of structural engineering expertise in the petroleum industry strongly resembles the slippery slopes that characterised the cultural processes leading up to the Challenger accident (Vaughan 1996).

The second category of contributing factors consists of deficiencies related to the integration between the different phases, from choice of concept to operation of the facility, and between the different actors involved in this process. The choice of the concept, design, and construction of an offshore facility is a complex engineering process. The need for specialised competence implies that the process will, almost by definition, involve a large number of organisations.

Despite all the advances in information and communication technology, this still involves a fragmented organisational setting where the integration of the process is bound to be a challenge. Moreover, the process stretches over a long period of time, creating some challenges in the flow of information and feedback possibilities between the actors involved. Finally, the geographical difference (and the corresponding different time zones), as well as the cultural complexity involved, means that a seamless coordination, integration and follow-up is very hard to achieve. Figure 3 gives an overview of the afore-mentioned contributing factors.

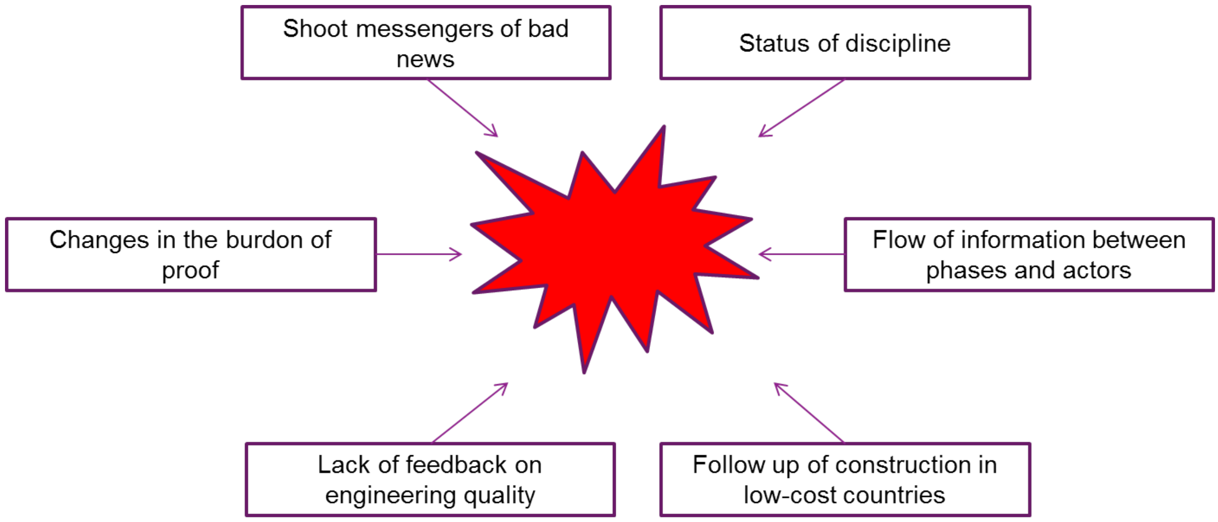

Figure 3: Organizational factors that can contribute to major accidents related to structural integrity

The above figure illustrates that the factors all point in the same direction and, as such, could be said to constitute latent organisational preconditions for a major accident. Put differently, this could be a model of the root causes of a future major accident related to structural integrity.

Our informants describe a development in which several of these challenges are becoming increasingly worse. This could be seen as a form of drift, where we gradually accept less robust concepts, more organisational complexity in the engineering/construction, and more complications related to quality assurance and follow-up. The worst case scenario would be that this constitutes a drift into 'latent failure' that could result in a disaster occurring sometime in the future. We must stress that we have no evidence that this *will* happen. Without the benefit of hindsight, all we can do is make a case for what are *possible* combinations of current challenges, those that may turn out to cause bigger problems in the future.

It is the role of safety research to help proving our worst fears to be wrong. Therefore, we suggest a number of improvement measures that may serve to change the direction and drift away from disaster.

5.1 Recommendations

5.1.1 Increase the quality of volume of investigations into structural incidents

One of the study's main findings is linked to the quality and quantity of investigations. Investigations are performed to map and describe the triggering and underlying causes of incidents, and as a basis for preparing risk-reducing measures in order to prevent similar incidents occurring in the future. Good investigations will also be able to contribute to organisational learning beyond the framework of the incident itself. For example, if an investigative process of a structural incident results in better insight into the lack of experience transfer between participants, improvement work may be able to prevent a series of incidents caused by the same organisational failings.

From a major accident perspective, investigations also have a supplementary function. Major accidents are rare occurrences. The investigations of incidents, and the ensuing information provided to relevant groups of participants, therefore constitute an important tool for maintaining vigilance in safety work. There are also regulatory requirements demanding that safety-critical information is collected, processed and communicated, and that personnel must have received training in relevant risk factors. It is appropriate to use investigations for this purpose.

- Operating companies and rig owner companies, in cooperation with relevant authorities, should assess whether more structural incidents could be investigated. The criteria for when such investigations are undertaken should be reviewed, and an assessment made of which investigation methodology is best suited to yielding a better understanding of structural-related incidents.
- Measures should be undertaken to raise the quality of investigations of mobile facilities. Consideration should, for example, be given to establishing a shared pool of investigative resources which small and medium-sized rig owner companies could make use of. This could contribute to raising the expertise of all participants over time and may also improve the quality and utility of investigations from different companies.

5.1.2 A better understanding if and how the use of detailed software calculations can affect structural safety

A number of interviewees were concerned that detailed software calculations can jeopardise the robustness of constructions by undermining the engineer's conceptual understanding, reducing safety margins and making structures over-analysed and under-designed.

There was diverging feedback on this issue from the respondents. While some expressed concerns regarding reduced margins and safety in structures, others considered more detailed calculations the means of achieving safer solutions. Based on our findings it seems clear that more knowledge is required to determine if and how the use of detailed software calculations will affect structural safety.

- Opinions in the industry are divided on whether improved analytical tools produce more or less robust structures. It is recommended that the concept of robustness be clarified in the regulations and structural standards. It is, in any case, crucial to maintain engineering expertise in order to safeguard the understanding of the potential and limitations of the analytical tools involved.

5.1.3 Systematic safety work and major accident prevention

This study has identified that the structural engineering profession is under pressure, recognising that there is a need to ensure that assessments from the structural engineering profession come to the fore in the relevant organisations, in order that dilemmas between, for example, costs and design choices be resolved appropriately and prudently, so that any tendency to drift into failure is detected and corrected.

- The petroleum industry should ensure that structural engineering expertise and evaluations are seen as key elements in major accident prevention work. They should therefore ensure that proper handling of conflicting goals in structural issues is an integrated part of the efforts to create and maintain a good safety culture.

5.1.4 Improve information exchange between participants and between different phases

The study has revealed that there exists a need to strengthen information exchange between participants and between different phases of a facility's life cycle. Efforts must be made towards attaining improved information exchange between engineering companies and operating/rig owner companies by, for example, detailing how conceptual choices and technical solutions work in the field, or through strengthened practice in using data from decommissioned facilities as a source of empirical knowledge. Good information exchange between participants and phases also requires that there be adequate resources made available for performing good follow-up work in the design and fabrication phase.

- New forums should be created, or existing ones strengthened, in order to facilitate discussion and interaction between the participants in the structural engineering profession.

- More systematic transfer of experience from operating and rig owner companies to the engineering companies should be established. This will contribute to a greater degree of learning in the engineering companies and better structural solutions, both conceptually and at detailed design level. For example, there is a need for:
    - Information for the engineering companies about how the inspection work is performed in practice (according to which methods and measuring points)
    - Communication of findings from investigation reports
    - Communication of operational experience

- There is a need for better follow-up of engineering companies and yards from the requisitioners of facilities. When contracts are awarded to engineering companies and yards that have little or no experience of the NCS, it is recommended that the follow-up of structural safety and marine systems be reinforced.

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